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(Vol. IX.—March, 1880.)

# INTER-OCEANIC CANAL PROJECTS.*

By FERDINAND DE LESSEPS, J. DIRKS and V. DAUZATS.

M. Ferdinand de Lesseps, having accepted the invitation to attend a meeting of the Society, and intimated his preference to be first introduced to the American public by the Civil Engineers, a special meeting of the Society was held in New York, on the evening of February 26th, 1880, at the theatre of the Union League Club. The attendance was large, comprising many members of the Society, leading citizens and invited guests, many of the latter being ladies.

## Introduction by O. CHANUTE.

Vice-President O. Chanute was in the chair, and after calling the meeting to order, said:

This is a special adjourned meeting of the American Society of Civil Engineers, held for the purpose of welcoming to the United States the distinguished Engineers who have just arrived from Central America, and of hearing what they wish to say concerning the American Inter-Oceanic Canal. We shall first be addressed by M. de Lesseps. As, much to his regret, he does not speak English, his communication will be made in French, and, at his request, a synopsis of each portion of it will be made in English by Mr. N. Appleton. M. de

*Inter-Oceanic Canal Projects, by A. G. Menocal, Vol. VII, p. 311 (November, 1879). Discussions on the subject, Vol. IX, p. 1 (January, 1880), and Vol. IX, p. 47 (February, 1880).

Lesseps will also answer any questions which may be asked. After he has terminated, we shall have an account of the works proposed, by Mr. J. Dirks, Chief Engineer of the canal from Amsterdam to the sea.

The American Society of Civil Engineers has heretofore endeavored to contribute its share toward the understanding of the subject of the Inter-Oceanic Canal, by gathering information concerning the various routes, the plans proposed for the canal, their probable cost, and the commercial bearings of the project.

This it has done, not with a view to revising the plans of what is, after all, a private enterprise; nor to pass judgment upon them, for the Society commits itself, as a body, to no views, and neither for nor against any project, but rather to collect the data required, that its individual members might form an intelligent opinion concerning the merits and probable results of an important undertaking, in which the American public is to be invited to take a share.

Beginning in November last, with the reading of a paper upon "Inter-Oceanic Canal Projects," by Mr. Menocal, member of the Society, and one of the delegates to the Paris Congress, the discussion has been participated in by many prominent members of the Society, as well as by several gentlemen who promote particular routes, and we have been fully informed concerning the San Blas, the Nicaragua, and the Tehuantepec routes.

But little has yet been said in these discussions concerning the Panama route; it being generally felt, that pending the proposed revision of the location and of the plans for the canal, by the very able engineers who had the matter in charge, it was desirable, before any opinions were expressed, to await the announcement of the results.

We are now able to learn these results, as well as the facts and plans upon which they are based, in the most direct, certain, and satisfactory manner; for we have among us to-night, as a guest, the chief manager and promoter of the enterprise; a gentleman of world-wide fame, as the builder of the Suez Canal, who, having already accomplished labors which to other men would be the work of a lifetime, having connected in the face of the most strenuous difficulties, two great seas across the trackless sand of the desert, now proposes to perform the still greater feat of cleaving the American Isthmus asunder, to connect the two great oceans of the world. Gentlemen, I have the honor to introduce to you M. Ferdinand de Lesseps.

Discussion by M. FERDINAND DE LESSEPS.

Mr. President and Members of the American Society of Civil Engineers, Ladies and Gentlemen: I am very happy to be here this evening, not only because it gives me an opportunity to set forth my views on the great project which I have so much at heart, and which I think when completed will be so great a blessing to mankind, but also at finding myself immediately upon my arrival in America, the much honored guest of this Society of Civil Engineers, before which, above all others, I consider it proper that I should first address myself. I am not an engineer by education, having been for so many years in the profession of a diplomatist, yet I am happy to be received as an engineer, and I am happy on that account as well as for the personal honors which have been paid me and the many opportunities afforded me for seeing in the short time I have already spent on shore what were to me most interesting and instructive illustrations of American engineering, skill and science.

I desire to begin at the beginning. In 1870, soon after the completion of the Suez Canal, and after that work had begun to be put into regular use, I began to think seriously upon the question of an inter-oceanic canal across the narrow land separating the two oceans in the Western Hemisphere. The first difficulty was the supposed difference in the levels of the two seas. An impression that there was such a difference had gone out and in many quarters was seriously believed, though for what reason I could not find out. Upon a careful examination it was discovered that this difference of sea-level was a myth, and that the only basis of the myth was the ebb and flow of the tide, which differed on the two sides of the Isthmus, but which would make no difficulty in the construction of a sea-level canal—for that from the first was the sort of a canal on which I had set my heart, and which I will build or abandon the project. I will not take up the various steps through which we passed in the consideration of this problem, for I can assure you that there were much study and many investigations during the years intervening between my first determination on the subject and the present time.

I determined not to occupy myself with political opinions, but from the moment I began the enterprise to devote myself to the practical part of the undertaking. I looked at the subject from a commercial view.

I am convinced and persuaded that the enterprise will be not only for the great advantage of commerce, affording an easy route to the Asian continent or India or Japan, but will produce results which will

develop the shipping interests of the United States to the place they occupied twenty-five years ago.

I had the honor of the acquaintance of Senator Sumner when he visited France, and he gave me many valuable figures on the state of American shipping at that time. He stated that the tonnage of American commerce at that time was about 5 500 000 tons. England at the same period had about 5 000 000 tons. All the commerce of the earth could have been divided into three sections, America owning one, England another, and all other nations together having an amount about equal to that possessed by each of these. Since that time America has fallen away as regards maritime commerce, and especially since the opening of the Suez Canal. Its commerce is very low, much more so than it should be for a people so great and powerful as the Americans. But I reflected that this was not to remain so; it cannot remain so with the Panama Canal open to encourage American shipping, as it certainly will do.

The Suez Canal has had the effect of changing the commerce of the whole world, and improved its shipping to an extent altogether unanticipated. It has caused the building of large steam vessels, which have supplanted the sailing ships. You will see that a similar metamorphosis will follow the opening of a Panama Canal. American shipping has fallen off since the war, and the mercantile marine, I am informed, is now in a deplorable condition. The opening of such a canal would give a fresh impetus to the building of American shipping and assist you in regaining the position that you have lost. To-day I say to the American people, prepare yourselves in six or seven years to see your commerce extended from the North Pole to the South. When you shall have comprehended the importance of the canal you will see that your commerce will be benefited according to your large population, and that no other country will have pre-eminence over you when the canal is opened. I work not for selfish motives, but for the interests of humanity. Should you not, therefore, concur in the project as other countries have done?

I will compare the Suez Canal with that proposed at Panama, and show, as I hope, that the one across the Isthmus would be an easier matter than that joining the Red Sea and the Mediterranean. In the first place, there was no precedent for the Suez Canal in modern times. The ground had been a battlefield of nations since the commencement of historic times. In the time of the Pharaohs, there were fresh water canals in Egypt, in the construction of which the natural watercourses were often utilized.

The first canal proposed for crossing the Isthmus of Suez was in the time of Philip II. He at first acquiesced in the idea, but being a very jealous monarch, and afraid that other nations might profit by the canal, he afterwards insisted that the project should be abandoned. An edict was issued declaring all men impious who should propose such a canal. Even if they spoke about it they were to be put to death. This was his order, and as they knew he had the power to carry it out, the subject of the canal was quickly dropped. I hope the example of Philip II. will not be followed in America. It would be very inconvenient for some of us to have such an edict in force.

Since the time of Columbus there have not been wanting those who thought that the American Isthmus could be traversed. It was first thought feasible by using the natural ports, lakes and rivers. The regular study of the question of the inter-oceanic canal began in 1875. There was then at Paris a universal geographical congress, and there I talked with Professor Nourse, from your Government offices in Washington, and I discovered how much interest was felt in the canal in America. I was charged to preside over the inter-oceanic section, and I obtained from Washington all the plans of proposed routes. Of all countries the most concerned was America. Some said that America did not want the canal, but I replied, "You deceive yourselves. America wants to develop commerce in the entire world." To prove that America wanted the canal, perhaps I exaggerated a little, but I said that she had spent already about $1,000,000 in exploration and in the attempts to find out how to start right in this great work. I said at the Conference that America having built a line of railroad across the Isthmus, it was a good argument in favor of crossing it at that point. The American engineers chose this route thirty years ago, and built their railroad there.

A new congress was proposed, to which that special question of the canal was to be referred. I wrote a number of letters to leading engineers in Europe and America, inviting them to come to Paris to discuss this scheme. Every one came at his own expense, and the first engineers of Europe were there. Over one hundred persons were present, the èlite of the entire engineering world. We were divided up into sections, one on engineering, one on navigation, one on statistics, one on the movement of commerce, and one on finances. Each committee commenced its work without wasting any time. I said we should go to work

*a l'Americaine.* "How is that?" they asked. "Quickly," I said. And after what I saw yesterday, I can say that I never before knew fully what it was to speak of anything being *a l'Americaine.* Now I know what it is when I see your bold street elevated road and your magnificent bridge and your other works of freedom in science.

At it we went for fifteen days, night and day. All our deliberations were afterward printed. I remember that in connection with the Congress something was said to the effect that the American delegation was not treated with due consideration. This was an erroneous idea. Admiral Ammen was made First Vice-President. I do not think any discussion was started that the Americans were not in courtesy first called upon to speak upon it, and when it came to the final vote, every man could vote as he pleased, and also give in writing his reasons for the vote. There was not only no disfavor shown the Americans, but I was even charged with showing partiality to them, and this charge will be found in the printed report of the proceedings. At the final vote, 78 voted for the Panama route and 8 against, 12 declining to vote. I did not expect until the last day to occupy the place I now do at the head of this gigantic work, but when I heard the exclamations of the Congress, and saw there before me, as I see it now, the face of my wife, I felt that I ought to put myself at the head of this work, and the completion of the circumnavigation of the globe.

I thought, moreover, I had not the right, after having gone so far, to refuse to see the work through. It would have been cowardice not to continue, so I advanced in spite of the opinion of Mme. de Lesseps. It has brought now the pleasure of a visit to America, and the enjoyment of the hospitalities which are now showering upon me, and which I should not otherwise have enjoyed.

The first thing after this was to get the concessions from the Compagnie Civile, which that body had secured from the State of Colombia. My plan was to offer the company $1 000 000 in cash when the subscription for our undertaking should be taken up, and $1 000 000 in the stock of the new company. This new company has not succeeded, partly on account of the opposition of the press, and the press is a great power and deserves to direct public opinion when it is managed by honest men. The subscription was not a success, and I paid back the money to all who had subscribed. Thereupon some of my friends came together, and placed $400,000 in my hands to enable me to verify the surveys, and

to pay the deposit required by the Colombian Goverment. I could not have done this with my own means. I am not ashamed to say that I have no fortune. I have passed twenty years in diplomacy and thirty years in engineering, but I did not profit by any of the enterprises which I began. It is not my trade ; I make it a principle not to gain anything from others. I have only the shares which I pay for myself. Those who invested their money in the enterprise have taken a great risk and have a fair right to the fruits of success. Now my work has commenced of executing the enterprise. It is a work of the entire world, not only for other nations, but especially for America.

Let us talk of the technical part. Determined to make a verification of former surveys upon which I had based my scheme, I repaired to Panama with a party of ten well-known engineers. The expedition to the country has been safely accomplished, notwithstanding the dangers forboded to us. Much has been said against the climate of Panama ; but we did not suffer from it at all. The climate of Suez is infinitely worse. The heat at Panama is from 23° to 33° Centigrade; at Suez 30° to 35°. We all came back in safety. The country was not dangerous at all, and was much more favorable to such an undertaking than that surrounding the Suez Canal, which I will now tell you of. The most celebrated engineers of France and England did not expect such a great success. I was treated as a fool because I simply desired to cut away the earth, whereas they had expected I would make a canal with the assistance of the Nile. I took engineers there and we occupied the territory. There was no water near, no houses, and it was nothing but a great plain of sand, containing nothing that could be of use to us. We used camels, and our laborers were divided in companies, some going in search of water while the others worked. There are no rains at Suez; it never rains there. The difficulties were almost insurmountable. There were battles with workmen, water had to be carried sixty leagues, we had fierce storms to encounter, and for the first two or three years we scarcely got a foothold. The sand did not frighten me as it did the public. It did not take much trouble to remove it, of course, and most of it was done by hand, before we had machines. But the taking out of clay was a more serious undertaking ; in some respects it was more difficult to deal with than stone, because it could not be blasted or removed in blocks. Suez was far worse than Panama can be. We remember how we were told most solemnly that Suez could not be built, but

we went, I shall say again, *a l' Americaine*, and did it, and now we propose to do it again. I have shown you the difficulties at Suez; at Panama there are no such difficulties.

Now (referring to a model in relief, of the proposed line of the Panama Canal), I will briefly sketch the route for the canal: It begins on the Atlantic side, at Colon (Aspinwall), and joins the valley of the River Chagres, a little south of the bay of Limon. The River Chagres however, does not empty into the Bay of Limon, but into the sea at the old town of Chagres. The canal follows the valley of this river to a point near Matachin, where the river has a sharp turn towards the northeast, and runs between two mountains. Here the canal leaves this valley, and it is proposed to construct a dam between these two mountains to provide for the storage of the flood waters of the river. This dam will be forty meters in height, and will retain about one thousand millions cubic metres of water. There are at least three dams in the world, which are of equal magnitude with this, and which have stood for many years; one in Spain is higher, and has endured three centuries.

The canal, leaving the valley of the Chagres, cuts through the mountains at Culebra, where the extreme depth of cutting will be about 270 feet, almost exactly the same as that of the towers of your great Brooklyn bridge, which you have just kindly shown us. Thence the canal will follow the valley of the Rio Grande to the Pacific, which it enters near the City of Panama.

Another advantage possessed by the Isthmus of Panama over that of Suez is its fertility, being a perfect paradise; there is no botanical garden in the world which could surpass it in beauty. The stations on the American railroad are surrounded by villages, and there is plenty of game in the mountains. I leave to the engineers with me the explanation of the details of the proposed plan, who will report as to the country which they have passed through, and after they have finished I will be at the disposal of the public to respond to all questions which any one may choose to ask.

Now, I beg to present this model to the Society of Civil Engineers, and to thank them for this opportunity of addressing you.

Discussion by J. DIRKS.

In the first place I beg to call your attention to the fact that neither the English nor the French is my native language. For this reason I invoke your kindness in overlooking any mistake as regards pronunciation; also grammatical errors. M. de Lesseps, the great mind who pulled down the Suez barrier, and therefore deserved, as well as earned, the thanks of mankind in general—came to America with the object of removing a second barrier, in joining together both oceans by a great ship canal through the American Isthmus. Allow me, ladies and gentlemen, to explain, in a few words, why M. de Lesseps deemed it convenient to invite me to join, not alone the Paris Congress of May last, but the scientific and technical survey of the canal line between Colon (Aspinwall) and Panama, which took place during the last few weeks. I have the advantage of being the engineer of the ship canal going from Amsterdam to the sea, which canal is fully described by your esteemed countryman, General Barnard, and was visited as well by himself as by other engineers of this great country, among them Captain Eads, the renowned builder of the St. Louis Bridge and of the wonderful works at the mouth of the Mississippi. When the general plan of the Amsterdam Canal was proposed, about 1860, only very few engineers believed in its feasibility, and the majority of scientific men were of opinion that a sea harbor in the shifting sands of the broad and shallow beach at the North Sea, as well as the dredging of a canal in the very soft mud of the lake through which it ran, were to be considered as quite impossible. Belonging to the small minority who were convinced that the Amsterdam Canal could be made and would fully answer the purpose, I was charged with the execution of the whole, in conjunction with Sir John Hawkshaw, from London, who acted as consulting engineer.

It is a great satisfaction to me that the Amsterdam Canal has been constructed; that the dark forebodings of a large majority never were realized; that the canal, at a cost of about $16 000 000, is a complete success, and that the largest vessels, even to a draught of twenty-four feet, easily enter and leave the new North Sea Harbor and get to Amsterdam within four or five hours. If not for the results of this proportionally smaller, but nevertheless very important scheme, M. de Lesseps would very likely never have known even my name. I have to thank him here for his kind opinion regarding the little experience in canal matters that I may have got, and I beg to state at the same time, as recorded above,

that I was not alone in my quality of acting chief engineer, but that the great mind of my friend, John Hawkshaw, was there also, in order to avoid or to put aside many difficulties of planning and construction. As regards the technical possibility of a level ship canal between both oceans at Panama, I am happy to say again what I told a few days ago to some very competent men, namely, that I would like to write down my very favorable opinion in very large characters and put at stake my reputation as an engineer that the difficulties of this enormous work will be not greater—perhaps even less important—than those of the Suez Canal and of so many other great works completed with full success in America and in Europe. I want to state that the making of a deep cutting is just as possible at Panama as in the United States; that the blowing up of rocks may be done there even with greater facility than at Hell Gate, near this city, and, finally, that the only serious technical question to be solved is that of the floods of the River Chagres, through the alluvial and present bed of which a great part of the ship canal will have to be led. But even that difficulty can be surmounted. The result of the studies of Colonel Totten and Mr. Dauzats, who went into the question with the utmost care, was set forth in the international report recently published, and known, as I presume, to the members of this scientific body. I may therefore confine myself to the renewed expression of my heartfelt thanks to the chairman and the members of the American Society of Civil Engineers, as well as to many other citizens of this great city. They show their regards and kind sympathy not only for the engineer but also for the Dutchman. They talk feelingly about the old ties between my country and the United States. The same old blood is running through the veins of many on both sides of the Atlantic, and what happened in past times may lead toward what may occur in the future, the relations between both peoples and the other nations will be progressing forever, and each barrier pulled down on the broad way of commerce and industry will largely contribute toward such a blessed prospect.

O. Chanute.—M. de Lesseps is now prepared to answer questions, and I will begin by asking him, what are the estimates of the probable cost of the undertaking, and the probable returns ?

M. De Lesseps.—One hundred and sixty-eight millions of dollars. Of this $20 000 000 are for the large dam to keep the waters of the River Chagres in. It would not be necessary to have the work entirely com-

pleted before vessels could be sent through. I am satisfied, too, that the final operations will show a considerable reduction. This is the reason that induces me to fix the capital at 600 000 000f. or $120 000 000. But should my hopes in this direction not be fulfilled, the difference necessary to make up the estimate can be supplied by bonds or otherwise.

According to the returns of the Congress at Paris, it was calculated by M. Levasseur, the Chairman of the Committee on Statistics, that 6 000 000 tons would pass through the canal in a year, and that within ten years they would rise to 7 250 000. At Suez the tariff was 10 francs or $2 per ton, but at Panama it could be raised to $3, which would give a gross yearly revenue of $18 000 000, which would be a very large return for a capital of $200 000 000, which is much more than the canal is estimated to cost, including the running expenses and the interest on the money. And as this tonnage is greater than that which was estimated to pass through the Suez Canal, the canal on this continent would be a better investment than the other, and the stock and bonds of the Suez Canal are very much above par.

O. Chanute.—What proportion of the necessary capital will be raised in Europe, and how much do you propose to raise in this country?

M. De Lesseps.—The original capital will be $120 000 000. One-quarter has to be paid up before a company can be formed under the French law. One-half of the capital stock will be allotted to the United States, and the other half to Europe. But in case it is not taken up by the United States I will try and have the sixty millions taken up in some other way. But I wish to have it understood that one-half the stock may be subscribed for in the United States, as the United States have an interest in the enterprise equal to all the rest of the world put together.

Horatio Allen.—Past president of the Society:—I would like to ask a question, so that we may have a little clearer conception of the subject. I understand that the length of the canal from ocean to ocean will be forty-five miles; that a certain portion of that canal will be a deep cut, and that a certain other portion will be ordinary canal work. I would like to ask how many miles are to be cut through, and how many will be a deep cut?

V. Dauzats.—The deep cutting extends for about six and a half or seven miles. The deepest excavation will be about ninety metres; and for this distance of seven miles the cutting may average about 180 feet. In other parts of the canal the cutting will not be of very great depth.

HORATIO ALLEN.—Is the deep cutting entirely in rock?

V. DAUZATS.—Not entirely in the rock. There is earth over the rock. Col. Totten thinks that the earth may be twenty feet in depth, but in order to be safe the estimate was based on a depth of earth of twelve feet and the remainder rock.

Q. A. GILLMORE.—Will you give some details as to the proposed dam for the Chagres River?

J. DIRKS.—The height will be 40 metres and the length 1 600 metres. It will form a reservoir capable of holding more water than the greatest flood known on the river. Before a second flood arrives the reservoir could be emptied by the main and the secondary canals. The dam can be sufficiently well built to make it perfectly safe.

ASHBEL WELCH.—Why go to the enormous expense of making a sea level canal across the Isthmus when a canal with two or three locks on each side of the deep cut could be made so much more cheaply?

M. DE LESSEPS.—If the Commission of Engineers which had gone down to Panama had reported in favor of a canal with locks I should have put on my hat and left the whole project and would have had nothing to do with it. That plan may do for small ships, but when we have vessels now afloat 500 feet long and others on the stocks 600 feet long, it is impossible to say for what you would have to build the locks. Single locks would be slow, and double locks though quicker would be very expensive and require constant repairs. At Nicaragua they intended the use of locks, and with the earthquakes which prevail there the repairs would be ruinously expensive, and even at Panama, where earthquakes do not exist, they would be fatal by reason of the loss of time. I would not have anything to do with a locked canal except for little ships. It is not the proper idea for a grand inter-oceanic canal.

C. BUTLER asked why the San Blas route has not been examined.

M. DE LESSEPS.—The object of the commission was to examine the line accepted by the International Congress; but in reference to the route referred to by the gentleman, I would say, that although the port on the Atlantic side is very good, that on the Pacific side is not. This line would make necessary a tunnel of, say, seven miles in length, and as the commission had already rejected a route in which there would be a tunnel of three or four miles, why adopt one having a tunnel so much greater in length?

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CLXXXIX.

Vol. IX.—March, 1880.

## THE ENGINEERING PROBLEMS INVOLVED IN THE PROPOSED IMPROVEMENT OF THE ERIE CANAL BY INCREASING THE DEPTH OF THE CHANNEL ONE FOOT.

By E. SWEET, Jr., C. E., Member of the Society.

PRESENTED AT THE ELEVENTH ANNUAL CONVENTION, JUNE 17TH, 1879.

The vast economies accruing to rail transportation in recent years from improved administration, depreciated cost of materials and labor and increased durability and effectiveness of machinery and permanent way as well as the improvements being effected in rival water routes, have so threatened the usefulness and permanence of the New York Canal system as to stimulate the friends and patrons of our canals to investigate the improvements most likely to insure their continued supremacy.

The limitation imposed by the State Constitution of 1874, upon canal expenditures which permits no outlay for repairs and improvements upon the canals in any year beyond the gross revenues of the preceding year, as well as physical and economic difficulties environing

the location and termini of the Erie Canal, alike forbid the contemplation of any radical change or any extensive enlargement in it.

For this reason it becomes necessary to confine our attention to improvements which do not necessitate extensive changes in its important structures, its locks, aqueducts, reservoirs and feeders.

These conditions, coupled with the fact that the present large tonnage of the canal consists of boats which almost universally have capacity for a foot greater draft of water without change, have directed attention, by common consent to confining the improvement of the prism to securing an additional foot in depth of water.

To determine the commercial value of this improvement involves the solution of three problems: 1st. What will it cost? 2d. What increased capacity of tonnage, and what decreased cost of transportation will it effect? 3d. Will the present water supply be adequate for the improved canal?

1st. The data for determining the first question are furnished in great detail and in the most available form by the profiles and cross sections and other records of a survey of this canal made by direction of State Engineer Van Buren, during 1876. This survey comprised accurate test levels the whole length of the canal—cross sections at intervals of 66 feet of the prism and banks and the location, dimensions, details of construction and condition of all its structures.

It first became necessary, however, to decide upon the manner of deepening, that is, whether to excavate the bottom of the present channel or to raise its banks. A superficial inspection of the cross sections, diagrams, and of the elevations of the permanent structures, convinced me that the process of raising the banks involved a very much smaller quantity of earth work and far less radical and expensive changes in structures than that of excavating the bottom, and produces nearly twice as great an enlargement of the waterway on account of the slopes and the necessity of leaving benches at the foot of the old walls. The importance of this difference arises from the fact that the resistance to the propulsion of boats in narrow channels diminishes as the water section increases.

The masonry of nearly all the locks, aqueducts and waste weirs is already high enough, and the embankments are generally wide enough to give the requisite height and width to the new banks without adding to their side slopes. Another fatal objection to excavating the bottom is,

that a considerable part of the canal is carried artificially above the surface of adjacent lands, and has its bottom lined with impervious materials to prevent leakage, and consequent damage to farms and other improved property. Excavating the bottom would be a source of danger to all this property as well as to the security of the canal itself, unless the expensive process of additional excavations and replacing the impervious materials on a lower plane were resorted to.

We have, therefore, made estimates for raising the water surface a foot.

This involves the raising of the superstructures and approaches of all bridges, gates of locks, trunks of aqueducts, crests of water weirs, and slope and vertical walls, spillways, and the berme and towing-path embankments, as well as the taking up and relaying of pavement wall and vertical wall-coping on the new towing-path angle.

The estimates are for a towing-path lined with gravel 9½ feet above canal bottom on the inner, and 9 feet on the outer angle, and 12 feet wide, and for berme embankments 9½ feet above canal bottom and 10 feet wide, and to be constructed from materials obtained from the bottom of the prism.

The quantities of all the items of work thus required have been computed in detail, and adequate prices applied to each of them.

The aggregate estimated cost thus derived for the entire work, including a liberal allowance for engineering and contingencies is $1 146 571 45.

2d. The second question—the probable effect of this deepening upon the economy of transportation, depends upon the relative capacity and the relative resistance of boats moving in the present canal, and like boats moving in the deepened channel.

The capacity of boats loaded to run equally near the bottom of the new as of the old channel is evidently increased by the water displaced by the foot additional submersion, amounting to about 1 650 cubic feet, or a little more than fifty tons.

The other branch of this question—the relative resistance offered by the two channels to the movements of boats is a far more complicated problem, the discussion of which is the principal object of this paper.

There is no important problem in hydrodynamics that has received so meagre inductive treatment as this, relating to the propulsion of vessels in narrow channels.

The only experiments on this subject sufficiently comprehensive for

deducing the law of resistance in such channels, are, so far as I know, those of Du Buat and D'Aubuisson. The deductions of these eminent specialists are, however, widely at variance one with another, and with the facts observed as to the propulsion of vessels on our canals.

With a view of obtaining accurate information upon this subject, a series of experiments were made in the fall of 1877, by Resident Engineer Godwin, by direction of ex-State Engineer Van Buren, and a more comprehensive series have been made by me by direction of his successor, Mr. Seymour.

Mr. Godwin's experiments were made with light and loaded boats towed singly and in pairs (one behind the other), partly by horse power, but mostly by a small screw propelled tug. They were made at velocities from 1 to 3¾ miles per hour, and in canal channels of sections varying from 4.09 to 5.61 times the submerged section of boat, and in the broad expanse of the Hudson River.

The resistances were measured by a dynamometer and the speed through the water by an ordinary self-recording tachometer.

These experiments indicated a much higher resistance for the boats towed in the canal by tug than for those towed by horses at the same speed, showing that the current induced by the screw greatly increased the normal resistance of the narrow channel, therefore making all the tug experiments valueless for the purpose of determining the law of this resistance.

Inconsistencies in some of the results obtained both in the experiments made with horses and with the tug, attributable to the inaccuracy of the tachometer, and the small number of the experiments with horse-towed boats, showed the necessity of more extended experiments under more favorable conditions.

Instructed by this preliminary work of Mr. Godwin's, and provided with a dial reading tachometer designed by him, whose revolutions were recorded by electricity under the eye of the observer on the boat, we continued these experiments for two weeks on that portion of the Erie Canal between Canajoharie and Mindenville, New York.

This portion of the canal was selected as the site of the experiments, for the reason that nearly two miles of the level between Canajoharie and Fort Plain are shown by recent soundings to have a section equal and similar to the average channel which would be attained by the proposed deepening, while four miles of the canal at Mindenville very accurately represent the average section of the present canal.

The channels thus selected were subdivided by prominent stakes set 500 feet apart to guide the observers in regulating speed, and to diminish the liability of error in recording the observed resistances.

The canal boat, "Henry L. Purdy," chartered for the purpose of making these experiments is of 240 tons burthen, 96 feet 8 inches long, and 17 feet 7 inches beam, and in model fairly represents the boats in present use on the canal.

She was towed by horses, the resistance measured by a dynamometer and her absolute velocity through the water, determined by the above described tachometer. The co-efficients for deducing the velocity of current from the revolutions made and recorded by this apparatus were deduced by the method of least squares from a series of observations showing its rate of revolution in currents of different velocities, whose rates were simultaneously measured by other means.

The boat was first accurately loaded to a draft of 6 feet, when seven experiments were made in the standard section of the canal 7 feet deep, covering a distance of 50 100 feet, and at velocities ranging from 1.27 miles per hour to 1.95 miles per hour. Then with the same draft of water eleven experiments were made in the enlarged section 8 feet deep, covering a distance of 71 700 feet, and with a range of velocity from 1.39 to 2.09 miles per hour.

The boat was then loaded to 6½ feet draft of water and moved over 24 400 feet of the channel 8 feet deep, at velocities from 1.46 to 2.24 miles per hour, and lastly, loaded to 7 feet draft, towed ever 15 000 feet of the 8 feet channel, at velocities from 1.33 to 2.00 miles per hour. The greatest practical difficulty in this class of experiments arises from the essential lack of uniformity in motion produced directly by animal locomotion. In each of these experiments great care was therefore taken to maintain as nearly uniform a velocity as possible over its entire course, in order to secure probable accuracy in the observed resistance derived from equating a great number of readings from the dynamometer made at short equal intervals of time.

The following tables present the results of all these experiments which are free from known errors, simplified by equating and consolidating the results of those in which the conditions were identical, and in which the velocities varied less than 3 per cent.

## Traction Experiments on the Erie Canal, 1877 and 1878.

| Name of Boat. | Time. | Distance in Feet. | Absolute Velocity. | | Sections. | | Ratio of Boat to Prism Section. | Depth of Water. | Immersion of Boat. | Weight of Boat. | Weight of Cargo. | Resistance | | Component Parallel to Motion of Boat. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feet per Sec. | Miles per Hour. | Immersed Of Boat. Sq. Ft. | Prism. Sq. Ft. | | | | | | Observed in Pounds. | Computed by Formula $R = \frac{0.10303\, sv^2}{v - .597}$ | |
| | H. M. S. | | | | | | | | | | | | | |
| **With Horses in Canal near Canajoharie, Aug. and Sept., 1878.** | | | | | | | | | | | | | | |
| Henry L. Purdy | 0 45 45 | 5 104 | 1.86 | 1.27 | 105 | 450 | 4.28 | 7 ft. | 6 ft. | 130 000 | 467 600 | 297 | 278 | 292 |
| " " " | 1 55 20 | 18 753 | 2.71 | 1.85 | " | " | " | " | " | " | " | 575 | 590 | 564 |
| " " " | 2 32 58 | 26 249 | 2.86 | 1.95 | " | " | " | " | " | " | " | 634 | 657 | 622 |
| " " " | 1 4 50 | 7 935 | 2.04 | 1.39 | 105 | 525 | 5. | 8 ft. | 6 ft. | 130 000 | 467 600 | 292 | 280 | 286 |
| " " " | 0 35 50 | 5 720 | 2.20 | 1.50 | " | " | " | " | " | " | " | 343 | 326 | 336 |
| " " " | 2 23 34 | 33 612 | 2.30 | 1.57 | " | " | " | " | " | " | " | 381 | 356 | 374 |
| " " " | 2 0 43 | 20 860 | 2.88 | 1.96 | " | " | " | " | " | " | " | 594 | 558 | 583 |
| " " " | 0 19 31 | 3 583 | 3.06 | 2.09 | " | " | " | " | " | " | " | 645 | 629 | 632 |
| " " " | 0 53 44 | 6 899 | 2.14 | 1.46 | 113.75 | 525 | 4.61 | 8 ft. | 6.5 ft. | 130 000 | 521 120 | 369 | 344 | 362 |
| " " " | 0 42 20 | 7 467 | 2.94 | 2.00 | " | " | " | " | " | " | " | 632 | 656 | 620 |
| " " " | 0 42 31 | 8 010 | 3.14 | 2.14 | " | " | " | " | " | " | " | 734 | 733 | 720 |
| " " " | 0 13 41 | 1 601 | 1.95 | 1.33 | 122.5 | 525 | 4.28 | 8 ft. | 7 ft. | 130 000 | 574 740 | 350 | 330 | 343 |
| " " " | 0 55 04 | 9 714 | 2.94 | 2.00 | " | " | " | " | " | " | " | 678 | 718 | 665 |
| " " " | 0 23 13 | 3 691 | 2.65 | 1.81 | " | " | " | " | " | " | " | 602 | 607 | 590 |
| **With Horses in Canal near West Troy, Nov., 1877.** | | | | | | | | | | | | | | |
| S. Evans..... | 0 3 30 | 551.6 | 2.11 | 1.44 | 105 | 490 | 467 | 7.5 | 6. | 129 000 | 459 600 | 316 | 323 | 304 |
| A. H. Smith.... | 0 2 00 | 330 | 2.47 | 1.68 | 102 | 572 | 567 | 7.5 | 5.9 | 119 000 | 434 310 | 365.5 | 358 | 354 |
| S. Evans..... | 0 6 00 | 1 194.6 | 2.80 | 1.91 | 105 | " | 545 | " | 6. | 129 000 | 459 600 | 452 | 476 | 435 |
| T. C. Davis.... | 0 1 24 (?) | 330 | 3.59 | 2.45 | 106.4 | 470 | 442 | " | 6.1 | 116 600 | 459 200 | 523.6 | .... | 504 |
| **With Tug in River near Albany, Nov., 1877.** | | | | | | | | | | | | | | |
| R. W. Stroud... | 0 12 50 | 2 625 | 5.03 | 3.44 | 51 | | | 12 ft. | 2.9 | 120 000 | 140 000 | 693.8 | .... | ... |
| S. Evans..... | 0 7 00 | 2 760 | 4.94 | 3.37 | 105 | Infinite. | Infinite. | " | 6.0 | 129 000 | 459 600 | 1 094.8 | ... | .... |
| Freddie..... | 0 3 00 | 1 275 | 5.45 | 3.72 | 111 | | | " | 6.3 | 138 500 | 479 940 | 1 307 | .... | .... |
| " ..... | 0 6 05 | 2 625 | 5.54 | 3.79 | " | | | " | 6.3 | " | " | " | .... | .... |

In the last column of the tables I have introduced the theoretical resistances for each rate of speed, with the given ratios of prism to boat sections and extent of immersion computed by a formula which I have deduced analytically from these experiments.

In making this deduction I have assumed that the analytic expression for the law governing the resistance of boats in narrow channels is of the general form indicated by the investigations of Scott Russell and Du Buat, viz.: $R = \frac{av^2s}{r+B}$ in which $R$ represents the resistance, $s$ the submerged surface of the boat, $v$ the velocity, $r$ the ratio of the channel's water section to the immersed section of boat, and $a$ and $B$ constants determinable by experiment.

Using feet, seconds, and pounds as units, I have applied the method of least squares to the observed values of $R$, $r$, $v$ and $s$, and in all the experiments of 1878, and thus determined the most probable values of $a$ and $B$.

These values are $a = 0.10303$, and $B = -0.597$.

$$\text{Therefore, } R = \frac{0.10303v^2s}{r - 0.597}.$$

On comparing in the tables the observed resistances with those computed by this formula it will be seen that in the experiments made with horse power the differences are slight and readily explained by the difficulty already mentioned, of accurately recording the rapidly varying power exerted by animals.

As before explained, the resistance encountered by the boats propelled by the tug was considerably greater on account of the current induced by the screw. We may, therefore, conclude that the law of resistance within the limits of speed, depth of emersion and ratios of prism to boat section covered by these experiments is for boats of like model and condition of surface, expressed by the equation $R = \frac{0.10303sv^2}{r-0.597}$, the units being feet, pounds and seconds. For velocities in miles per hour, this becomes $R = \frac{0.2215\,sv^2}{r-0.597}$.

This formula is readily convertible into the special form given by Du Buat, $R = \frac{PA}{r+B}$ in which $P$ = the resistance of the boat at same velocity in an unlimited expanse of water where $P$ is supposed to be

known for any velocity—Du Buat assigns to $A$ the value 8.46 and to $B$ the value + 2.

Since both $P$ and $R$ vary as the square of the velocity, and as the area of the submerged surface, $sv^2$ is a function of both, $A$ in the latter formula $= \frac{a}{\frac{P}{sv^2}}$.

Taking the mean value of $\frac{P}{sv^2}$ derived from our experiments of November, 1877, in the river, for velocities, measured in miles per hour, we have $A = 6.70$ and the formula of Du Buat becomes $R = \frac{6.70P}{r - 0.597}$.

A close approximation to the value of $P$ may, doubtless, be obtained by applying Scott Russell's rule for vessel propulsion: $R = sv^2 [1 + (4 \sin^2 o) f]$, in which $s$ represents the submerged surface of the boat in feet, $v$, the velocity in miles per hour, $o$, the mean obliquity of the stream lines, and $f$ the co-efficient of friction for the vessel's surface moving in the water.

By a serious error in the determination of the stream line angles of the boat experimented with in August last, I was led to assign an erroneous value to $A$ in adapting this formula of Du Buat to the results of the above-described experiments, and to my regret it is perpetuated in the annual report of our State Engineer. A careful remeasurement of the boat's model enables us to derive almost precisely the same value for $A$ as that above obtained from the mean of our experiments in a wide expanse of water.

This remeasurement gives 0.526 as the mean value of $\sin^2 o$; substituting this value and the numerical values of $sv^2$ in Scott Russell's formula for $P$ and attributing to $f$ the value $\frac{105}{10000}$, we readily find the resistance the boat would encounter in an unlimited expanse under the conditions of load and speed occurring in any of the experiments. Substituting the value of $P$ thus obtained for any given experiment in the formula $R = \frac{PA}{r - .597}$, and attributing to $R$ and $r$ their numerical values for that case gives $A = 6.68$ or $R = \frac{6.68P}{r - .597}$.

These results indicate that at low velocities the effects of contraction are only felt in channels whose sections are less than 7.3 that of the boats propelled in them. They also show the resistance due to con-

traction to be greater than that found by Du Buat's formula, and that it increases as the ratio of the channel and boat sections diminishes more rapidly than that formula indicates.

We are now prepared to apply this law to the comparative resistance of loaded boats in the present canal, and in the canal deepened as proposed, and thus to determine the advantages of the proposed improvement.

Boats of the standard size and model now in use on this canal have horizontal cross-sections at and above the six feet draft line of a little over 1 600 square feet, and consequently carry a little more than 25 tons for every half foot submersion beyond 6 feet. The submerged surface of these boats, when drawing 6 feet, is about 2 870 square feet; when drawing 6½ feet is about 2 980 square feet, and when drawing 7 feet it is about 3 090 square feet.

The average rate of speed now attained in this canal by boats loaded to 6 feet, towed by two horses, deducting detentions, and making due allowance for currents, is 1.3 miles per hour. Their speed over the ground, however, is 1.54 miles per hour.

They encounter a resistance, according to the law above enunciated, of 292 pounds. The work performed by each horse is, therefore, 20 000 feet pounds per minute.

Two horses, each working at the above rate of 20 000 feet pounds per minute, would tow the boat thus loaded in the improved channel at the rate of 1.39 miles per hour through the water, and 1.63 miles per hour over the ground, encountering a resistance of 277 pounds, thus shortening the trip from Buffalo to West Troy nearly 12 hours.

If loaded to 6½ feet in the enlarged canal their resistance at a given velocity would be nearly 5 per cent. less than when loaded to 6 feet in the present canal; and two horses each working at the rate of 20 000 feet pounds per minute would tow the boat thus loaded in the deepened channel two per cent. faster than when loaded to six feet in the old canal. It also follows that a boat loaded to 7 feet draft in the improved prism, if towed at the above rate of 40 000 feet pounds per minute would move at the rate of 1.27 miles per hour through the water, and 1.51 miles per hour over the ground, with a resistance of 298 pounds. Its trip, therefore, from Buffalo to tide-water would be but little more than four hours longer than that of a cargo 50 tons lighter similarly towed in the present canal.

3d. The water supply.

The proposed deepening of the canal will affect the question of water supply in various ways. It will increase the waste from leakage, filtration and evaporation. The former by reason of the increased head in the levels, and the latter by enlarging their water surface.

It will also, by attracting a larger traffic, increase the demand for lockages, and by increasing the hydraulic mean depth, will create an additional demand to produce the rate of current most beneficial to navigation.

Assuming the apertures of escape to be equally distributed throughout the vertical height of the prism, the losses from filtration and leakage would be increased in the new over the old channel in the proportion of the square root of half the depth multiplied by the depth of the new to that of the old channel. And the losses from evaporation would be increased in proportion to the increase of the surface area. The increased loss due to both these sources will amount to about 18 per cent. of that sustained by the old canal, and added to the latter, will, probably, aggregate for each mile of canal, 250 cubic feet per minute.

If the canal be worked to its full capacity the demand for lockages is 5 500 cubic feet per minute on each declivity. The demand for dry docks and weigh locks may be estimated at 25 cubic feet per mile a minute.

The only other demand for feed water is for producing a beneficial current.

Until recently this important subject has been entirely overlooked on our canals. A very large portion of their tonnage moves eastward, and as the currents induced by the water fed to the Erie Canal are nearly all eastward, *i. e.*, in the direction of the heavy traffic, it is obvious that this may be made highly beneficial to navigation.

The following simple mathematical reasoning demonstrates the effect of currents upon boats differently loaded moving in opposite directions.

Let $L$ represent the length of the canal, $x$ the velocity of the current, $v$ the velocity through the water of the light loaded boat against the current, $v'$ the velocity of the heavily loaded boat moving with the current, $t$ the time required for the up trip, and $t'$ the down trip, and $T$ the time required for the round trip.

Then

$$t = \frac{L}{v - x} \quad t' = \frac{L}{v' + x} \text{ and } T = \frac{L}{v' + x} + \frac{L}{v - x}, \text{ or } \frac{L \quad (v' + v)}{vv' + (v - v')\, x - x^2}.$$

This equation representing the time of a round trip is evidently perfectly general and true for any assignable values of $v$; $v'$ and $x$. The greater value the denominator has the less $T$ becomes, and if $v$ be equal to or greater than $v'$, the value of the denominator is greatest when $x = o$, *i. e.*, when there is no current. Any current opposite the heavy traffic, therefore, prolongs the round trip. To find the minimum value of $T$, *i. e.*, the shortest round trip, it is only necessary to determine that value of $x$ which renders the denominator $v'v + (v - v')x - x^2$ a maximum. Differentiating this expression and making the first differential co-efficient $= o$, we have $x = \frac{v - v'}{2}$. As the second differential co-efficient is negative the value of $x = \frac{v - v'}{2}$ renders $T$ a minimum.

It follows that an uniform current in the direction of the heaviest traffic, having a rate equal to half the difference in speed of the loaded and unloaded boats through the water, insures the quickest round trip.

We will now proceed to determine, with reference to the deepened canal, the extent of this current, its effect upon transportation, and the demand which it will create for additional feed water.

It appears from the investigations of State Engineer Van Buren, published in his annual canal report for 1877, that, with an average easterly current of .24 of a mile per hour the average rate over the ground of boats towed by 2 horses going east is 1.54 miles per hour, and of those going west is 2.04 miles per hour. Without current the same effective duty of the animals would produce a speed of 1.38 miles per hour for boat loaded to 7 feet draft in the deepened prism going east, and 2.18 miles per hour for the boat carrying the usual load of 50 or 60 tons, going west, requiring 250 hours for the eastward trip, 158 hours for the return trip, and 408 hours running time for the round trip.

The most beneficial current determined by the above *formula* for boats thus loaded and drawn by two horses, each performing an effective duty of 20 000 feet pounds per minute, is .60 of a mile per hour.

At this rate the horses would move over the ground in both directions at the same speed, 1.8 miles per hour, and would encounter the same resistance, 260 pounds, thus requiring 191½ hours each for the up and down trip, and 383 hours for the round trip. Such a current would, therefore, effect a saving of 59 hours in the transfer of the principal cargo, and 25 hours in the time of making the round trip.

It is not practicable, however, to secure an uniform current of this extent throughout the Erie Canal, for the reason that considerable reaches have to be fed from one source, and that on about 15 per cent. of its extent the declivities are opposed to the direction of heavy traffic.

The present supply, however, by raising the Genesee River dam would be sufficient to give a current from .45 to .7, and averaging .60 miles per hour, from Buffalo to Montezuma, and from Little Falls to Albany, and of .30 miles from Rome to Little Falls. With the feed water reduced to the bare requirements of loss and lockage on the westward declivities these currents would make the running time of the above described boats, towed with two horses on the deepened canal, 201 hours going east, and 187 hours going west. Thus making the eastward trip, with 290 tons cargo, in 41 hours shorter time than is required in the present canal for a cargo of 240 tons, and the round trip in 22 hours less time than is now required.

I have dealt with the effects of this improvement on horse-towed boats, because 95 per cent. of our canal tonnage is towed by horses. That it will prove of still greater advantage to steam towing is obvious, as it renders possible the economical attainment of higher speeds than are permissible in the present channel.

The realization of this improvement would have enabled the boats which performed the carrying trade of the Erie Canal last year, employing the same force and the same crews, to have carried, without additional force, with less cost, and in less time, 650 000 tons more freight to tide-water, representing an additional revenue to the State, at present rates of toll, of over $200 000, and on the basis of prevailing freights a net gain to the boatmen of $750 000, besides the advantages to allied interests along the canal and at its *termini*. The benefits of a single year's business, therefore, promise to very nearly repay all the costs of the improvements.